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May 15, 2008

Project No. 8128.01.12

Mr. Dana Bayuk  
Oregon Department of Environmental Quality  
2020 SW 4th Avenue, Suite 400  
Portland, Oregon 97201-4987

Re: DEQ Comments on Siltronic FFS - Site-Specific Analysis of Iron  
Siltronic Corporation  
7200 NW Front Avenue, Portland, OR  
ECSI #183

Dear Mr. Bayuk:

Siltronic Corporation (Siltronic) received comments from the Oregon Department of Environmental Quality (DEQ) regarding the Focused Feasibility Study (the Siltronic FFS, submitted October 23, 2007) on of February, 14, 2008. The Siltronic FFS was prepared and submitted consistent with the requirements of the *Order Requiring Remedial Investigation and Source Control Measures*, DEQ No. VC-NWR-03-16 (the TCE Order). The Siltronic FFS recommended implementation of enhanced in-situ bioremediation (EIB) in the source area and at the riverbank (Alternative 3A). DEQ did not concur with Siltronic's recommended approach, and selected Siltronic's Alternative 2B (EIB use in the source area only).

In their comments, DEQ indicated that the decision to reject Alternative 3A was based on the potential for iron associated with EIB to interfere with the groundwater extraction remedy proposed by NW Natural (NWN). DEQ also indicated that the decision was based on the potential for EIB to result in releases of iron to the river, presumably through transition zone water (TZW) at Area 1, where the groundwater plume sourced at Siltronic discharges to the river.

On behalf of Siltronic, MFA prepared a response (dated March 6, 2008) to DEQ's comments that supported Siltronic's recommended approach. In subsequent meetings with representatives of the United States Environmental Protection Agency (EPA) regarding scope, schedule, and coordination of in-water remedies, EPA indicated that a comprehensive approach capable of integrating source control with an in-river remedy, similar to Alternative 3A proposed in Siltronic's FFS, would be preferred.

Siltronic understands that EPA and DEQ have scheduled a meeting on May 20, 2008 to further discuss DEQ's source control decision. Siltronic hopes that both agencies can agree on a comprehensive, sequenced source control approach that also addresses TCE-related risks in TZW. This letter provides additional site-specific data and analysis regarding characteristics and behavior of iron in the alluvial water-bearing zone in order

to facilitate and inform agency discussions, and address potential implementation risks associated with EIB.

In summary, the data presented herein demonstrate that implementation of an EIB permeable reactive barrier (PRB) remove iron from groundwater, thus preventing formation of well-fouling ferric hydroxide, and reducing potential flux of iron to the Willamette River. The potential implementation risks associated with iron from EIB at the riverbank are not significant, and DEQ's decision to reject EIB at the riverbank based on such possible risks should be reconsidered.

## NATURE AND EXTENT OF IRON

As discussed in the Siltronic FFS, iron concentrations in groundwater are significantly elevated, likely due to disposal of significant amounts of spent iron oxide waste (gas purifier box residue). Unlike liquid waste (which was disposed to the river prior to surface impoundment), spent oxide was stockpiled on site throughout the operating history of the Gasco manufactured gas plant (MGP). As discussed in Section 2.2 of the Siltronic FFS, the strong correlation between concentration and depth confirms that surface storage and disposal of spent iron oxide is the source of the elevated iron background conditions.

The iron oxide in the gas purifier boxes was used to remove undesirable byproducts, such as cyanide-forming compounds and sulfur. As a consequence, the spent iron oxide contained elevated levels of iron-cyanide complexes and oxidized sulfur (i.e., sulfates). Groundwater sampling data from the Siltronic monitoring program has documented elevated levels of cyanide and sulfate, in addition to iron.

Based on wells located on the Siltronic property, the site-specific background concentration of iron is approximately 46 milligrams per liter (mg/l). Based on data from WS-21-112 (located upgradient of the pilot study area) and WS-12-125, the riverbank background is approximately 37 mg/L. These concentrations are elevated relative to typical (i.e., not site-related) concentrations of iron in groundwater (Hem, 1985).<sup>1</sup>

Iron is also present in the MGP DNAPL (dense, non-aqueous phase liquid), confirming the source of the iron (i.e., former MGP operations). MGP DNAPL samples collected from WS-10-27, WS-11-125, WS-14-125, and WS-15-85 contained iron ranging from approximately 50 to 100 milligrams per kilogram (mg/kg), with the highest concentration found in WS-11-125 (106 mg/kg, November 2004). These data were presented to DEQ in 2007,<sup>2</sup> and suggest that a significant fraction of iron in groundwater may be occurring as complexes with dissolved organic carbon (DOC) resulting from degradation of aromatic hydrocarbons. Specifically, oxidized aromatic structures ("broken" benzene rings)

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<sup>1</sup> Hem, John D., *Study and Interpretation of the Chemical Characteristics of Natural Water*, US Geological Survey Water Supply Paper 2254, 1985.

<sup>2</sup> Data presented in the RI Report (MFA, 2007).

weakly chelate iron, but remain in solution. The presence of significant DOC components has resulted in enhanced solubility and distribution of iron.

Iron at the site is also present in groundwater as ferricyanide  $[\text{Fe}(\text{CN})_6]^{3-}$  and ferrocyanide  $[\text{Fe}(\text{CN})_6]^{4-}$  anionic complexes, consistent with the analysis presented in the FFS and subsequent comments, and consistent with other MGP sites (Ghosh et al., 2004).<sup>3</sup> These complexes are also known as strong-acid dissociable (SAD) cyanide, and are typically the dominant form of cyanide at MGP sites. Total cyanide in the MGP DNAPL samples referenced above ranged from 0.3 to 0.5 mg/kg, confirming the source of iron and cyanide at the site.

Finally, iron cations are present in groundwater in the ferrous (+2) valence state, consistent with the pH and oxidation-reduction potential (ORP) measured at the site. Upon exposure to oxygen, the ferrous iron is oxidized to ferric iron (+3 valence), forming ferric hydroxide, or  $\text{Fe}(\text{OH})_3$ . Ferric hydroxide is relatively insoluble, and forms precipitates responsible for fouling of groundwater treatment systems (Hem, 1985).

## MECHANISMS FOR IRON REMOVAL

Under conditions created by implementation of an EIB permeable reactive barrier (PRB), the nature and extent of iron present within the aquifer is changed. As presented in the Siltronic FFS, iron concentrations initially increase, followed by significant decrease. Importantly, concentrations decrease to below background conditions, suggesting that an EIB PRB will also beneficially impact elevated iron resulting from MGP waste disposal.

Based on the pilot study data, several mechanisms were identified that remove iron from groundwater following implementation of an EIB PRB – precipitation of siderite (iron carbonate), precipitation of Fe-Mn-CN complexes, and precipitation of pyrite and arsenopyrite. The removal of iron and the other species are clearly shown in the following Figure 1, which includes the average groundwater concentrations (log molar, or *M*) from the three riverbank pilot study wells (WS-22-112, WS-11-125, and WS-20-112).<sup>4</sup>

Figure 1 shows that the molar concentrations of iron decrease by more than an order of magnitude as iron reacts with dissolved carbonate, sulfur, manganese, cyanide, and arsenic and forms stable precipitates. These mechanisms are discussed further as follows.

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<sup>3</sup> Ghosh, R.S., Nakles, D.V. Murarka, I.P., and Neuhauser, E.F. 2004. Cyanide Speciation in Soil and Groundwater at Manufactured Gas Plant (MGP) Sites. *Environmental Engineering Science*, 21(6) 752-767.

<sup>4</sup> Data are included in Table A-1.

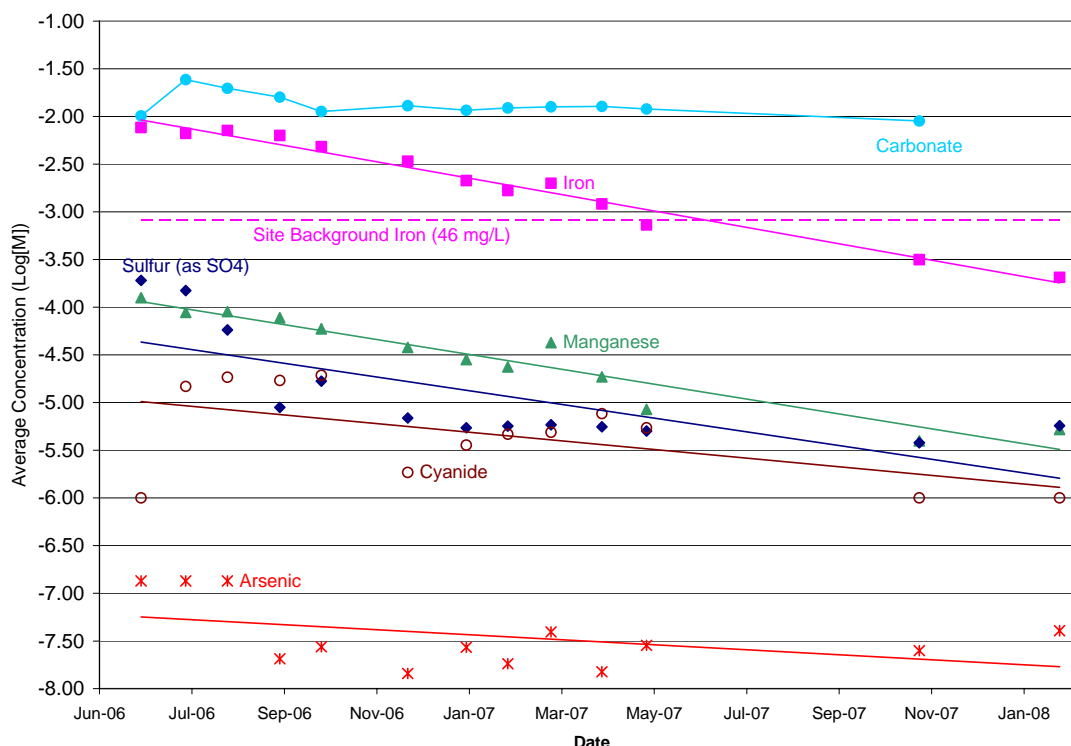


Figure 1. Average Groundwater Concentrations Following EIB PRB Implementation at Riverbank

### Siderite formation

Iron reacts with carbonate ( $\text{CO}_3^{2-}$ ) to form siderite ( $\text{FeCO}_3$ ), which is a stable precipitate. Figure 1 shows that carbonate concentrations remain stable and are greater than the iron concentrations throughout the pilot study. Excess dissolved carbonate is available in groundwater in the alluvial aquifer, such that additional iron due to the EIB PRB will continue to be removed from groundwater.

MFA and Adventus Americas, Inc. performed geochemical modeling using the US Geological Survey PHREEQC model.<sup>5</sup> The PHREEQC model can be used to predict the formation of minerals from dissolved ions in aqueous solution – in this case, predicting formation of iron minerals based on the concentrations in groundwater and the ambient conditions (including pH, ORP, alkalinity, temperature, and specific conductivity).

Data from WS-22-112, WS-11-125, and WS-20-112 were used to compare the saturation indices for siderite with those for ferric hydroxide (which is of concern with respect to potential iron fouling). Positive saturation indices indicate the solution is supersaturated with respect to the mineral in question, such that precipitation is predicted. Higher indices

<sup>5</sup> Parkhurst, D.L. and Appelo, C.A.J., 1999, User's guide to PHREEQC (Version2)—A computer program for speciation, batch-reaction, one-dimensional transport, and inverse geochemical calculations: U.S. Geological Survey Water-Resources Investigations Report 99-4259, 310 p.

support formation of increasing amounts of precipitate. Negative saturation indices indicate that the solution is undersaturated such that the precipitated (solid) phase will not form. The equation used to derive the saturation index is a logarithmic function, such that saturation index of 2 represents a significantly supersaturated solution.

Table 1 summarizes the results. The saturation indices for siderite are positive, predicting precipitation. The saturation indices for ferric hydroxide are negative, predicting that the primary iron mineral associated with extraction well fouling is not present and will not be precipitated under conditions created by the EIB PRB.

Table 1: PHREEQC Model Summary – Average Saturation Indices

Well	Saturation Index: Siderite (FeCO <sub>3</sub> )	Saturation Index: Ferric Hydroxide Fe(OH) <sub>3</sub>
WS-22-112 (PRB)	2.01	-4.48
WS-11-125	1.89	-4.68
WS-20-112	2.19	-3.33

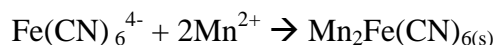
### Fe-CN/Fe-Mn-CN formation

Iron forms SAD CN complexes such as ferricyanide [Fe(CN)<sub>6</sub>]<sup>3-</sup> and ferrocyanide [Fe(CN)<sub>6</sub>]<sup>4-</sup>, which can be precipitated under reducing conditions by reacting with additional iron (Young et al. 1995).<sup>6</sup> The decrease in CN (present as HCN or weak complexes) shown in Figure 1 can be attributed to the additional iron from the EHC PRB, which forms strong CN complexes and subsequent precipitates, via the following reactions (Meeusen et. al, 1996):<sup>7</sup>



The simultaneous decreases of both iron and cyanide concentrations in groundwater confirms that these reactions are occurring, resulting in the formation of stable precipitates.

Precipitation of Mn along with the ferrocyanide complexes has been documented (Rennert, 2005)<sup>8</sup> under reducing conditions, via the following reaction:



<sup>6</sup> Young, C.A., Cashin, S.P. & Jordan, T.S. 1995. Remediation technologies for the separation and destruction of aqueous cyanide species. Preprint N° 96-149, SME, Littleton, CO.

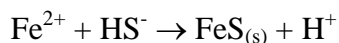
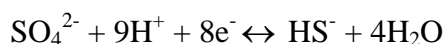
<sup>7</sup> Meeussen, J.C.L., Keizer, M.G., and de Haan, F.A. M., 1992. Chemical Stability and Decomposition Rate of Iron Cyanide Complexes in Soil Solutions. Environ. Sci. Technol., 26, 511-516.

<sup>8</sup> Rennert, T., and Mansfeldt, T., 2005. Iron-cyanide complexes in soil under varying redox conditions: speciation, solubility and modeling. European Journal of Soil Science, 56, 527-536.

Since the initial concentration of  $\text{Mn}^{2+}$  was much higher than that of CN, complexation by ferricyanide was one of the processes that controlled the observed losses in dissolved  $\text{Mn}^{2+}$  concentration. Additional losses of  $\text{Mn}^{2+}$  are likely attributable to the formation of  $\text{MnCO}_3$ .

### **Pyrite/Arsenopyrite formation**

Sulfate was reduced completely after the EIB PRB installation. Under reducing conditions, sulfate ( $\text{SO}_4^{2-}$ ) is reduced to sulfide ( $\text{S}^{2-}$ ). Precipitation of iron sulfides such as pyrite (and potentially mackinawite, pyrrhotite, or troilite) is the likely mechanism for the removal of S, via the following reactions:



Similar reactions remove iron, arsenic and sulfur from the groundwater by forming arsenopyrite ( $\text{FeAsS}$ ). However, arsenic concentrations are low relative to iron and sulfur, such that this process is not significant for iron removal.

The reaction pathway analysis demonstrates that multiple precipitation mechanisms can account for the decrease in iron and MGP-related inorganic anions. The PHREEQC modeling predicted removal of iron via the siderite formation process. The data confirm that iron is removed from the dissolved phase, and that excess capacity for precipitating iron is present in the dissolved phase. In short, the pathway analysis is supported by the model predictions, which in turn are borne out by the data.

## **POTENTIAL IMPACTS TO NWN SCM**

DEQ's comment related to impacts to the NWN SCM is:

*The data suggest to DEQ that iron concentrations have remained elevated at WS11-125, are migrating downgradient, and the reasons (e.g., geochemical, hydrogeological) are not yet understood. Based on this information, DEQ does not agree with Siltronic's conclusions that iron concentrations will rapidly decline or that downgradient migration of iron will not occur after EHC is injected. This comment also applies to discussions DEQ has had with Siltronic regarding the potential for iron released from EHC to foul extraction wells and treatment system components.*

It is important to note that iron concentrations in WS-11-125 subsequently decreased to background by February 2008. At no time did iron concentrations in WS-11-125 exceed the maximum upland concentrations (i.e., approximately 465 mg/L) that NWN has presumably designed their extraction system to treat. The FFS did not provide further evaluation of iron in WS-11-125 since data from WS-20-112 (located further downgradient and is more representative of potential downgradient distribution issues) and WS-22-112 (located within the PRB) demonstrated that EIB implementation does not result in significant, long-term elevated iron.

The elevated concentrations of iron in WS-11-125 are likely related to the presence of MGP DNAPL in that well, and the intrusion of EHC product into the well during injection. EHC was similarly observed in the soil cuttings collected during installation of monitoring well WS-20-112, which occurred following EIB PRB installation. Concentrations of iron in WS-20-112 were temporarily elevated, and then rapidly decreased. Absent the MGP DNAPL, the behavior of iron in WS-11-125 would be expected to be similar to WS-20-112. The difference in concentration patterns is best understood by the presence of MGP DNAPL (WS-11-125 had an [Fe]=106 mg/kg, November 2004), which is likely to have absorbed some EHC material, resulting in a slower release of iron. However, the ORP conditions that result in decreasing iron concentrations were only temporarily delayed, as shown on the following Figure 2.

The “buffering” effect in WS-11-125 was temporary. As shown on Figure 2, the reducing conditions (between -200 and -250 mV) were established and maintained in WS-22-112 and WS-20-112 sooner than in WS-11-125. In all three wells, significantly reducing conditions are established between -200 and -300 mV 18 months following injections.

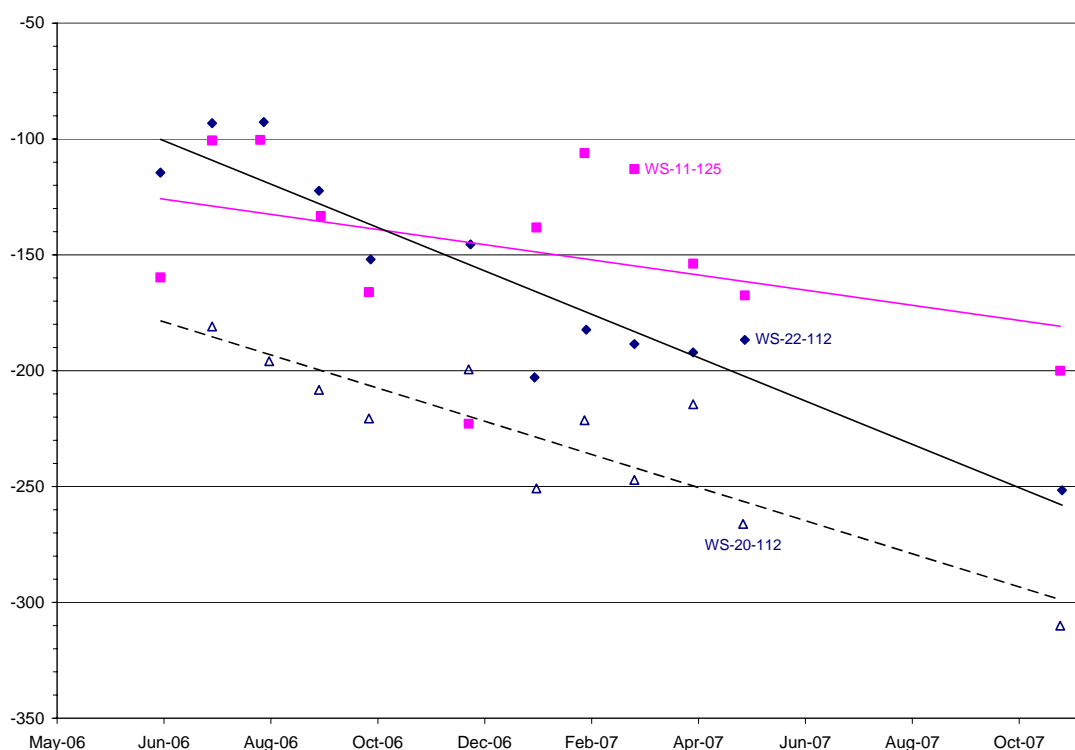


Figure 2: ORP Data (mV) from Riverbank Wells

With respect to DEQ’s concern regarding iron-related fouling, the MGP DNAPL present in WS-11-125 contains significantly elevated levels of iron regardless of EIB implementation. NWN has anticipated that elevated iron levels are present and has incorporated pre-treatment for iron in their design. Concentrations of iron in groundwater on the NWN property are much higher. The average concentration of iron along the

proposed groundwater extraction alignment in Segment 2 is approximately 73 mg/l; and the average concentration in groundwater from the Segment 2 riverbank borings (GS1 through GS6) is 420 mg/l.

Potential iron fouling of extraction wells is prevented or minimized by EIB implementation. The EIB PRB has been demonstrated to result in significant reducing conditions, such that iron in solution is present in the ferrous form. The reducing conditions should prevent the oxidation of iron to ferric hydroxide (the insoluble form), and minimize fouling of well screens. As shown on the following Figure 3, under the pH and reducing conditions established by an EIB PRB, iron will precipitate as siderite or pyrite, and ferric hydroxide will not be present or stable.

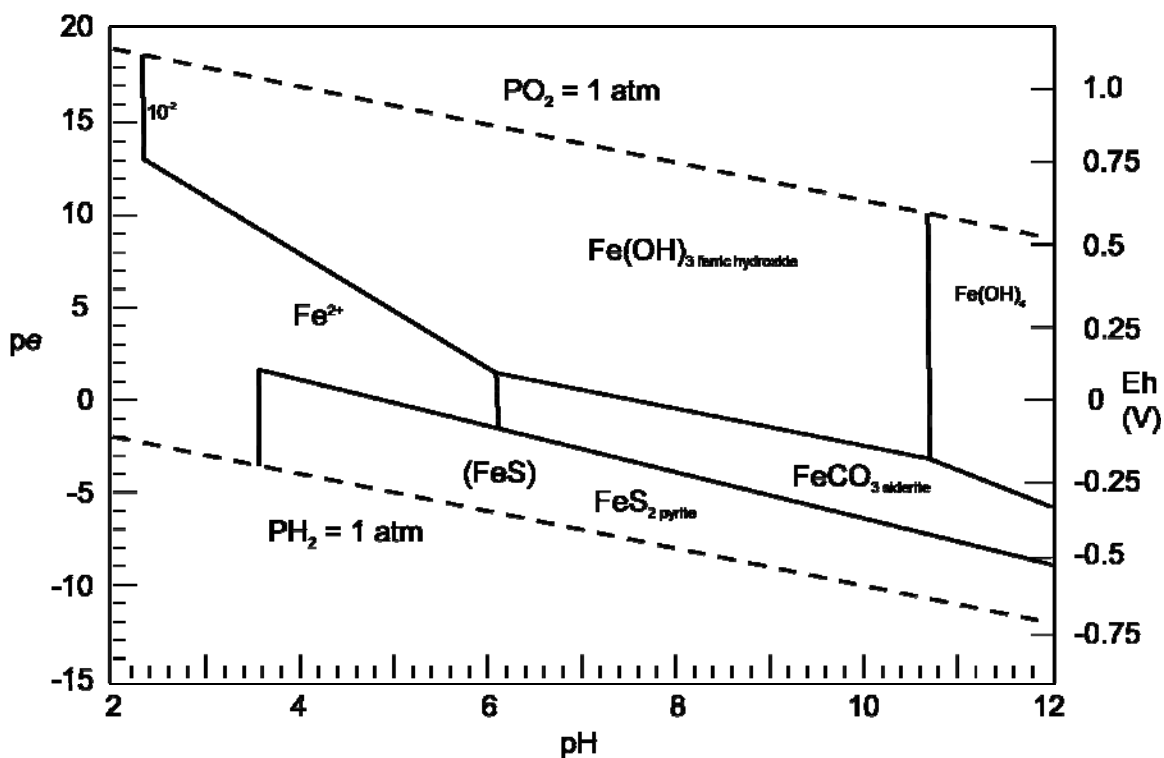


Figure 3: Eh-pH Diagram for Iron-Carbon-Sulfur Species (revised from Drever, 1997)<sup>9</sup>

Figure 3 shows that under the pH and ORP conditions established by the EIB PRB, and based on the concentrations of iron, carbonate, and sulfur observed in the riverbank wells, aqueous iron ( $\text{Fe}^{+2}$ ) forms stable precipitates such as siderite and pyrite, and is removed from solution. Background site conditions, with ORP ranging from -100 mV to 150 mV, will promote the formation of ferric hydroxide, which will likely foul extraction wells and equipment. With reducing conditions resulting from the EIB PRB, ORP ranges from -200 to -300 mV, removing iron from solution as siderite and pyrite are formed. Reducing conditions as a result of EIB PRB implementation are therefore *beneficial* with

<sup>9</sup> Drever, J.I., 1997. The Geochemistry of Natural Waters. Surface and Groundwater Environments. 3<sup>rd</sup> Ed., Prentice Hall, NJ, pp. 436



respect to improving extraction well performance by removing iron (regardless of whether it is from an EIB PRB or MGP-related waste) from solution.

Once an EIB PRB is appropriately sequenced and scheduled with groundwater extraction, elevated iron from the EHC product will not result in excess iron beyond the current NWN SCM design. On the contrary, requiring installation of the EIB PRB is an appropriate strategy to minimize fouling-related issues that are likely to occur due to high background iron conditions resulting from MGP waste disposal.

## POTENTIAL SURFACE WATER IMPACTS

In its comments, DEQ interpreted the data from WS-11-125 to suggest that downgradient distribution of iron could have potential impacts to the river. However, iron concentrations in the furthest downgradient monitoring well (WS-20-112) were reduced to below background levels within six months. Based on its proximity to the Willamette River, the data from WS-20-112 are most representative, and should be used to evaluate potential risk related to downgradient distribution.

The data from MGP analysis confirm the MGP DNAPL is a source of elevated iron, which partly explains the reason for the difference in the data sets. MGP DNAPL is likely present throughout the alluvial aquifer and represents an ongoing source of iron (in addition to other MGP-related impacts and iron sourced from the spent oxide) to the river. The reducing conditions established by EIB PRB implementation result in decreased concentrations of iron.

With respect to DEQ's concern that elevated iron from an EIB PRB could migrate downgradient and result in surface water impacts to the Willamette River, there is no evidence in the data to support such a conclusion, especially in consideration of the following:

- Elevated iron concentrations have been demonstrated to be temporary and are reduced to below site background levels by the formation of stable precipitates. The carbonate data show that excess capacity for buffering a temporary increase in iron is present between the proposed EIB PRB alignment and Area 1, where impacted groundwater discharges to the river.
- Concentrations of iron in groundwater offshore of Siltronic are elevated as a result of MGP waste. This iron is likely present as ferrocyanide / ferricyanide anions and as  $\text{Fe}^{+2}$  cations. Enhanced reducing conditions resulting from implementation of an EIB PRB would reduce the concentrations of iron and cyanide through formation of stable precipitates.
- Iron is not a constituent of concern for the Joint Source Control Strategy, while TCE and its degradation products are. While it is not established that the chlorinated VOCs in TZW in the middle of the navigation channel represent a risk to human health or the environment, implementation of the EIB PRB will

nonetheless eliminate these VOCs, and has been demonstrated to be successful in meeting the JSCS SLVs.

In their comments, DEQ indicated that they did not agree with the conclusions in the Siltronic FFS regarding downgradient distribution or potential iron fouling, and suggested that additional data collection would be required to support a site-specific analysis. The data and analysis presented herein represent a significant step forward in understanding the complex organic and inorganic geochemistry at the site.

The data indicate that the NWN SCM will encounter significant iron-fouling related challenges without implementation of EIB. The data also show that reducing conditions in the presence of excess carbonate and sulfur will result in removal of iron from the aquifer, and thereby prevent or minimize extraction well fouling due to ferric hydroxide formation. Proper sequencing as recommended by Siltronic will therefore minimize or eliminate concerns about interference.

NWN has proposed upland SCMs and an in-river removal action and has concluded that a sequenced EIB PRB at the riverbank would not be in conflict with its recommendations. Siltronic's recommended approach is consistent with EPA's stated desire for integration of the upland and in-river remedies for the Gasco and Siltronic sites.

The critical question remains as to how DEQ, EPA, and Siltronic should manage the potential risks associated with EIB and compare them to the potential risk associated with discharge of chlorinated VOCs to the Willamette River. Siltronic believes it has demonstrated that implementation risks due to an EIB PRB are unfounded. However, if DEQ and EPA agree that the risk of EIB implementation outweighs the risk associated with the chlorinated VOCs in the river, then such a determination should be documented prior to the Portland Harbor Record of Decision. If in-river impacts in Area 1 are to be addressed, upland source control via an EIB PRB is likely the only effective method for treating that portion of the chlorinated VOC plume that extends offshore beneath the river. In that event, DEQ should approve Siltronic's recommended approach.

Please call either of us at (971) 544-2139 if you have questions or comments.

Sincerely,

Maul Foster & Alongi, Inc.



James G.D. Peale, R.G.  
Senior Hydrogeologist



James J. Maul, R.G.  
Principal Hydrogeologist

Attachment: Table A-1 – Iron and Iron-Removing Species in Groundwater

Cc: Tom McCue, Siltronic  
Chris Reive, Jordan Schrader Ramis  
Alan Gladstone and William Earle, Davis Rothwell Earle & Xochihua, P.C.  
Bob Wyatt, NW Natural  
Sandy Hart, NW Natural  
Patty Dost, Schwabe Williamson & Wyatt  
John Edwards, Anchor Environmental, LLC  
Eric Blischke, EPA  
Rene Fuentes, EPA  
Chip Humphrey, EPA  
Kristine Koch, EPA  
Dick Pederson, DEQ/NWR  
Jim Anderson, DEQ/PHS  
Tom Gainer, DEQ/PHS  
Henning Larsen, DEQ/SRS  
Matt McClincy, DEQ/PHS

## TABLE

**Table A-1**  
Iron and Iron-Removing Species in Groundwater  
Riverbank Pilot Study Wells  
Siltronic Corporation  
Portland, Oregon

Well	Date	Carbonate (alkalinity, as CaCO <sub>3</sub> ) Total		Iron Dissolved		Manganese Total		Sulfate Total		Cyanide Total		Arsenic Total	
		(mg/l)	Log Molar	(mg/l)	Log Molar	(mg/l)	Log Molar	(mg/l)	Log Molar	(mg/l)	Log Molar	(ug/l)	Log Molar
WS-11-125	Jun-06	403	-2.18	168	-2.52	4.49	-4.09	7.17	-4.13	0.48	-4.73	<20.0	-8.18
WS-11-125	Jul-06	311	-2.29	118	-2.68	2.92	-4.27	10.8	-3.95	0.42	-4.79	<20.0	-8.18
WS-11-125	Aug-06	378	-2.21	135	-2.62	3.5	-4.20	4.95	-4.29	0.44	-4.77	<20.0	-8.18
WS-11-125	Sep-06	701	-1.94	173	-2.51	5.11	-4.03	0.78	-5.09	0.47	-4.74	1.58	-7.68
WS-11-125	Oct-06	695	-1.94	169	-2.52	5.9	-3.97	0.72	-5.12	0.48	-4.73	1.01	-7.87
WS-11-125	Dec-06	999	-1.79	315	-2.25	9.28	-3.77	2.15	-4.65	0.56	-4.67	1.14	-7.82
WS-11-125	Jan-07	976	-1.80	308	-2.26	10.6	-3.71	2.28	-4.62	0.38	-4.84	<1	-8.18
WS-11-125	Feb-07	1160	-1.72	327	-2.23	12.5	-3.64	2.57	-4.57	0.51	-4.71	<1	-8.18
WS-11-125	Mar-07	1300	-1.67	318	-2.24	12.8	-3.63	2.83	-4.53	0.51	-4.71	1.42	-7.72
WS-11-125	Apr-07	1420	-1.63	328	-2.23	12.7	-3.64	2.45	-4.59	0.61	-4.63	1.98	-7.58
WS-11-125	May-07	1560	-1.59	256	-2.34	8.98	-3.79	1.8	-4.73	0.42	-4.79	2.7	-7.44
WS-11-125	Nov-07	1070	-1.76	60.9	-2.96	1.45	-4.58	0.77	-5.10	0.56	-4.67	8.2	-6.96
WS-11-125	Feb-08	894	-1.83	42.8	-3.12	0.958	-4.76	0.55	-5.24	0.62	-4.62	9.5	-6.90
WS-20-112	Jun-06	771	-1.90	247	-2.35	5.54	-4.00	27.2	-3.55	0.47	-4.74	<20.0	-8.18
WS-20-112	Jul-06	2160	-1.45	296	-2.28	4.34	-4.10	16.3	-3.77	0.47	-4.74	<20.0	-8.18
WS-20-112	Aug-06	558	-2.04	286	-2.29	3.51	-4.19	5.5	-4.24	0.61	-4.63	<20.0	-8.18
WS-20-112	Sep-06	447	-2.14	132	-2.63	1.33	-4.62	<0.5	-5.60	0.49	-4.72	1.49	-7.70
WS-20-112	Oct-06	498	-2.09	120	-2.67	1.25	-4.64	0.95	-5.00	0.5	-4.72	1.15	-7.81
WS-20-112	Dec-06	488	-2.10	88.3	-2.80	0.207	-5.42	<0.5	-5.60	0.5	-4.72	<1	-8.18
WS-20-112	Jan-07	311	-2.29	61.3	-2.96	0.0962	-5.76	<0.5	-5.60	0.58	-4.65	<1	-8.18
WS-20-112	Feb-07	343	-2.25	36.9	-3.18	0.0404	-6.13	<0.5	-5.60	0.48	-4.73	<1	-8.18
WS-20-112	Mar-07	401	-2.18	52.6	-3.03	0.226	-5.39	<0.5	-5.60	0.49	-4.72	<1	-8.18
WS-20-112	Apr-07	289	-2.32	17.1	-3.51	0.133	-5.62	<0.5	-5.60	0.48	-4.73	<1	-8.18
WS-20-112	May-07	289	-2.32	7.01	-3.90	0.0154	-6.55	<0.5	-5.60	0.34	-4.88	<1	-8.18
WS-20-112	Nov-07	241	-2.40	7.23	-3.89	0.0109	-6.70	<0.5	-5.60	0.24	-5.03	<1	-8.18
WS-20-112	Feb-08	234	-2.42	29.9	-3.27	0.0191	-6.46	<0.5	-5.60	0.28	-4.97	<1	-8.18
WS-22-112	Jun-06	NA	NA	1890	-1.47	17.7	-3.49	31.5	-3.48	0.46	-4.75	<20.0	-8.18
WS-22-112	Jul-06	681	-1.95	1470	-1.58	11.4	-3.68	16.8	-3.76	0.39	-4.82	<20.0	-8.18
WS-22-112	Aug-06	1980	-1.49	1640	-1.53	9.72	-3.75	6.26	-4.19	0.57	-4.66	<20.0	-8.18

**Table A-1**  
Iron and Iron-Removing Species in Groundwater  
Riverbank Pilot Study Wells  
Siltronic Corporation  
Portland, Oregon

Well	Date	Carbonate (alkalinity, as CaCO <sub>3</sub> ) Total		Iron Dissolved		Manganese Total		Sulfate Total		Cyanide Total		Arsenic Total	
		(mg/l)	Log Molar	(mg/l)	Log Molar	(mg/l)	Log Molar	(mg/l)	Log Molar	(mg/l)	Log Molar	(ug/l)	Log Molar
WS-22-112	Sep-06	2670	-1.36	1920	-1.46	8.59	-3.81	3.21	-4.48	0.26	-5.00	<1	-8.18
WS-22-112	Oct-06	1770	-1.54	970	-1.76	3.51	-4.19	6.07	-4.20	0.54	-4.68	<5	-8.18
WS-22-112	Dec-06	870	-1.85	243	-2.36	0.384	-5.16	0.54	-5.25	0.6	-4.64	<1	-8.18
WS-22-112	Jan-07	883	-1.84	88.7	-2.80	0.112	-5.69	<0.5	-5.60	0.72	-4.56	<1	-8.18
WS-22-112	Feb-07	839	-1.86	67.5	-2.92	0.118	-5.67	<0.5	-5.60	0.64	-4.61	<1	-8.18
WS-22-112	Mar-07	743	-1.91	82.4	-2.83	0.489	-5.05	<0.5	-5.60	0.64	-4.61	<1	-8.18
WS-22-112	Apr-07	604	-2.00	54.7	-3.01	0.443	-5.09	<0.5	-5.60	0.73	-4.55	<1	-8.18
WS-22-112	May-07	619	-1.99	37.3	-3.18	0.0999	-5.74	<0.5	-5.60	0.49	-4.72	<1	-8.18
WS-22-112	Nov-07	344	-2.25	12.4	-3.65	0.0519	-6.02	<0.5	-5.60	0.65	-4.60	<1	-8.18
WS-22-112	Feb-08	327	-2.27	9.65	-3.76	0.0519	-6.02	<0.5	-5.60	0.66	-4.60	<1	-8.18

< Not detected above the reporting limit  
Non-detects fixed at low log M concentrations  
NA - not analyzed